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# LAG-SCREW JOINTS: THEIR BEHAVIOR AND DESIGN<sup>1</sup>

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## INTRODUCTION

Lag screws are commonly used because of their convenience, particularly in places where it would be difficult to fasten a bolt, or where a nut on the surface would be objectionable. Attachment of lagging, wood braces, skids to heavy machines for shipment, or fastening shaft hangers to joists or other supports are familiar examples of these uses. Safe loads for such connections, when computed by the methods given in various textbooks and handbooks now in use, differ widely. This lack of agreement is attributed to the fact that no extensive series of actual strength tests of ordinary lag-screw joints, from which safe working stresses might be determined with assurance, has heretofore been made.

The purpose of this bulletin is to present the results of numerous lag-screw tests recently made at the Forest Products Laboratory as a part of a more general investigation of wood joints and fastenings. The large number and range of the tests, the improved facilities and technique employed, together with the correlation of the results with those previously obtained from a comprehensive series of tests of bolts that simulate closely the action of lag screws, permit definite deductions to be drawn.

The tests cover two main aspects of lag-screw use and action; resistance to direct withdrawal, and resistance to lateral displacement.

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<sup>3</sup> Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

The lag screws used in the tests were purchased from local hardware stocks. They were of the machine-threaded type (fig. 1) with a root diameter of thread approximately three-fourths that of the shank or unthreaded portion. They differed widely in quality of metal and in over-all length, and also in the relative length of shank and threaded portion, particularly among the various sizes. In fact, there appears to be no well-recognized standard of design or quality for lag screws.

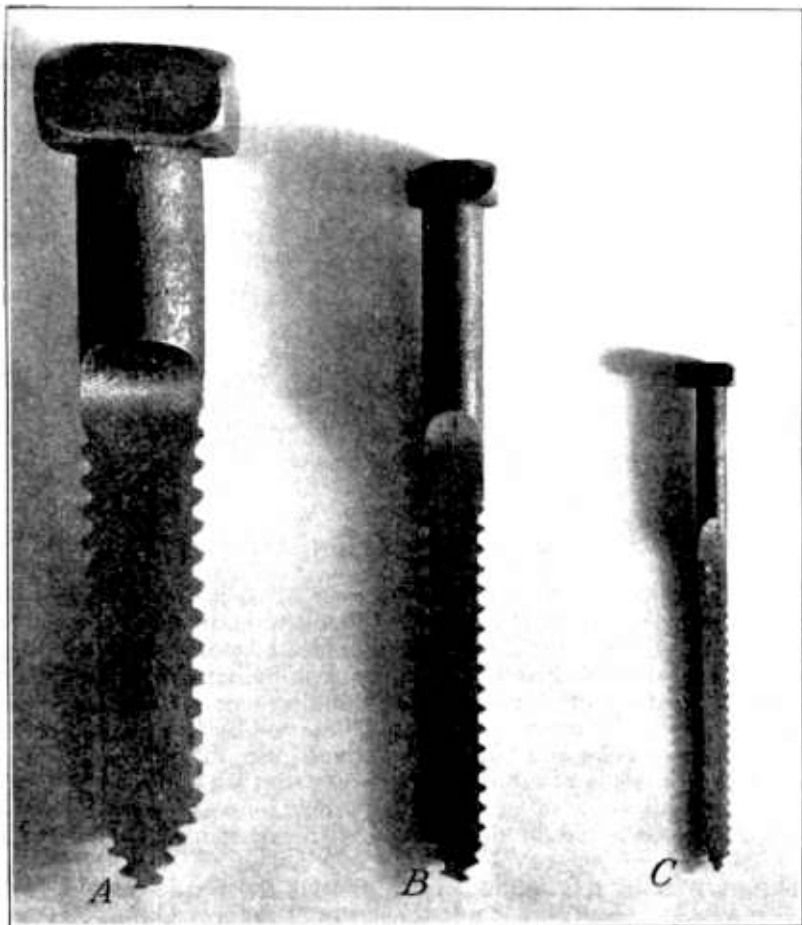


FIGURE 1.—Type of lag screws tested: A, 1-inch; B,  $\frac{3}{4}$ -inch; C,  $\frac{1}{2}$ -inch. The screws shown have been cut down in order to show the detail of the thread design.

In analyzing the results adjustments were made to compensate for some of the more serious of these variables.

Seasoned material of both coniferous and hardwood (broad-leaved) species was used in the study. At the time of test there were some slight variations in the moisture content of the specimens, but no tests were made to determine directly the effect of these differences on the results. Previous tests on the direct withdrawal of ordinary screws, and on the lateral resistance of nails and bolts, show that within a relatively narrow range in variation, a difference of 1 percent in mois-

ture content of the wood made a difference of about 2 percent in the results for the screws, and 3 percent for the nails and bolts.

### DIRECT WITHDRAWAL OF LAG SCREWS

Northern white pine, redwood, Douglas fir, southern yellow pine, and white oak, covering a wide range in density for each, were used in the tests. Some of the wood was not of high grade, but care was used in preparing the specimens to eliminate defects, particularly near where the lag screws were to be driven. The specimens were of sufficient width and length to permit the driving of screws of different diameters in each, thereby avoiding, to some extent, the effects of variation in quality between specimens and also between different parts of the same piece. The correct margin to use with different sizes of screws and with different species was not determined but the effect of this variable was eliminated in the tests by providing ample

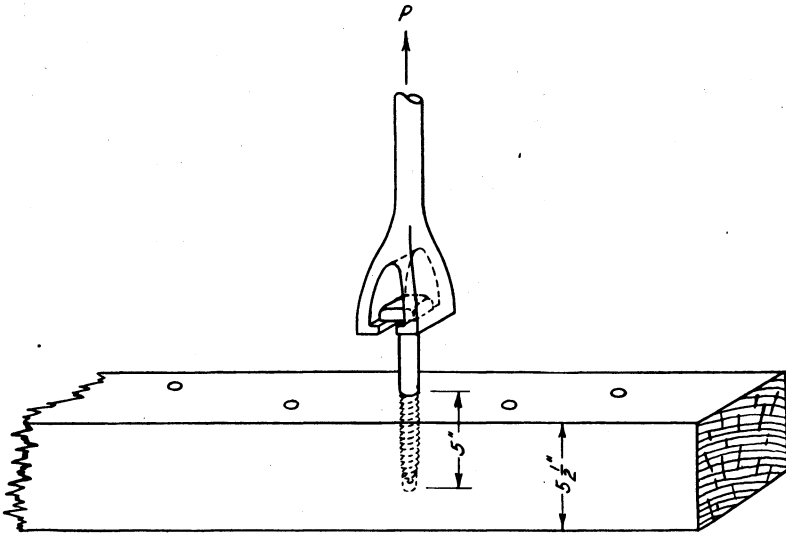


FIGURE 2.—Method of testing lag screws for direct withdrawal.

space between screws and also at the sides and ends of the test specimen.

The tests were made on a laboratory testing machine equipped with a special device for engaging the screw head, as shown in figure 2. The speed used in the tests was 0.041 inch per minute.

In the major tests only the maximum withdrawal loads were recorded. Moisture determinations, specific gravity, and compression-parallel-to-grain tests were also made on control pieces which were representative in quality of the original specimens.

Three groups of direct-withdrawal tests were made; one set to determine the most efficient diameter of lead hole for each size of lag screw and for different species of wood; another to show the effects of different depths of driving; and a third to show how differences in diameter of lag screw and in the quality of the wood affect the resistance to direct withdrawal from either a side-grain or an end-grain

surface of the specimen. A lead hole of approximately the optimum diameter determined in the first set of tests was used in the subsequent groups. In all direct-withdrawal tests no portion of the shank made contact with the wood.

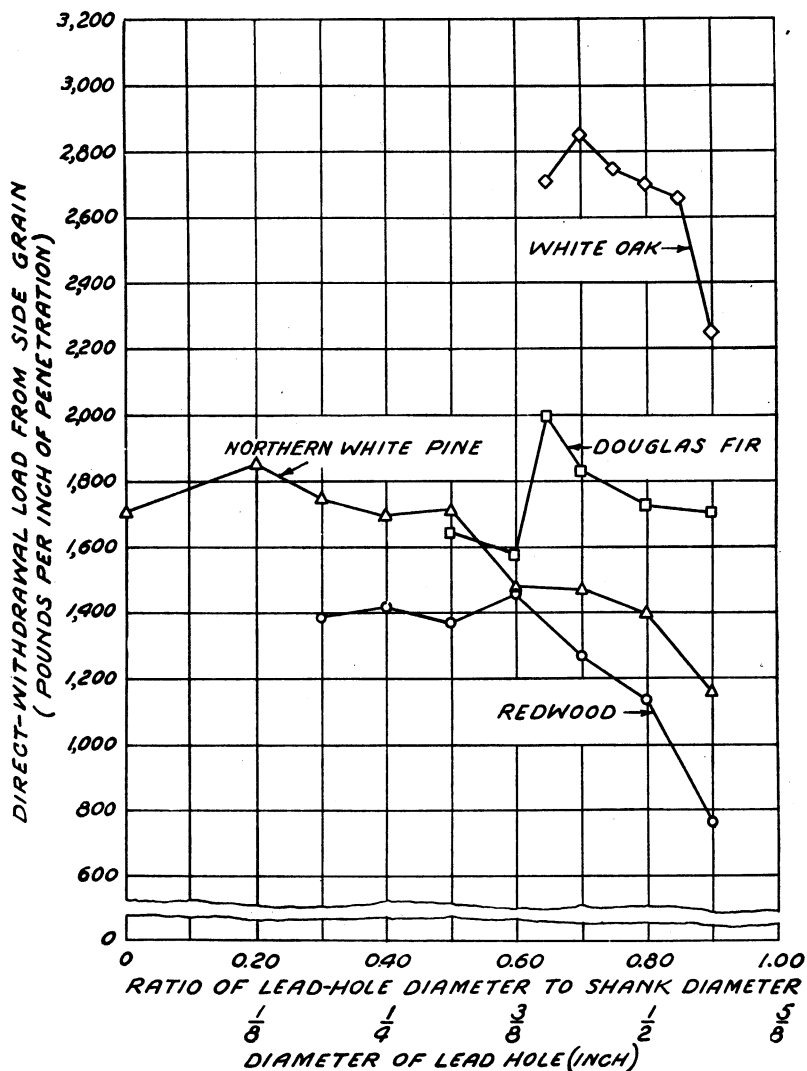


FIGURE 3.—Relation of direct withdrawal of a  $\frac{5}{8}$ -inch lag screw to diameter of lead hole, in air-dry wood.

#### FACTORS THAT AFFECT RESISTANCE TO DIRECT WITHDRAWAL OF LAG SCREWS

##### DIAMETER OF LEAD HOLE

Lag screws having a shank diameter of five-eighths of an inch were used with varying diameters of lead hole as shown in figure 3. For redwood an additional set of tests was made in which the diameter of lag screw as well as that of the lead hole was varied. Screws  $\frac{5}{16}$ ,  $\frac{3}{8}$ ,

$\frac{1}{2}$ ,  $\frac{5}{8}$ ,  $\frac{3}{4}$ ,  $\frac{7}{8}$ , and 1 inch in diameter were tested. The results for these additional tests of redwood are shown in figure 4.

It may be observed in figure 3 that for a  $\frac{5}{8}$ -inch lag screw used with white oak, a diameter of lead hole about 70 percent of the shank diameter of the screw is associated with the highest withdrawal loads; for Douglas fir, a diameter of lead hole 65 percent; with redwood a diameter 60 percent; and for northern white pine a diameter 50 percent or less. Additional tests show that the same range in diameter of lead hole as given here for Douglas fir also applies to southern yellow pine. Figure 4 shows how the most effective ratio of lead-hole diameter varies in redwood with different diameters of lag screw.

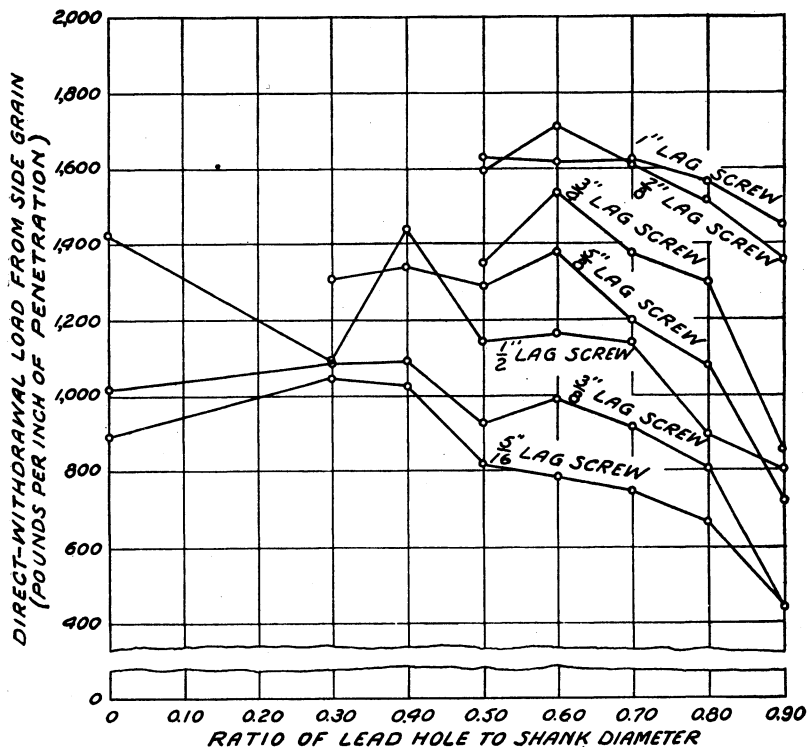


FIGURE 4.—Resistance to direct withdrawal of lag screws of various diameters in lead holes of different diameters, in air-dry redwood.

The optimum diameter of lead hole as related to diameter of lag screw appears to be neither a constant ratio nor is it less by a fixed amount. For all practical purposes, the most effective range in diameter of lead hole in white oak is 65 to 85 percent of the shank diameter of the lag screw; 60 to 75 percent for southern yellow pine and Douglas fir; and 40 to 70 percent for redwood and northern white pine. The wide spread in these ranges in ratio of lead-hole diameter to shank diameter is necessary because of the differences in diameter of screws to which they apply. The smaller figure in each ratio applies to lag screws of the smaller diameters and the larger figure to the larger lag screws up to 1 inch in diameter.

Figure 5 shows impressions left in the wood when lag screws were backed out after driving. The smooth, compact surface shown at *A* was made by a lag screw when driven into a lead hole of proper size. The condition of surface when the lead hole was too large is shown in *B*.

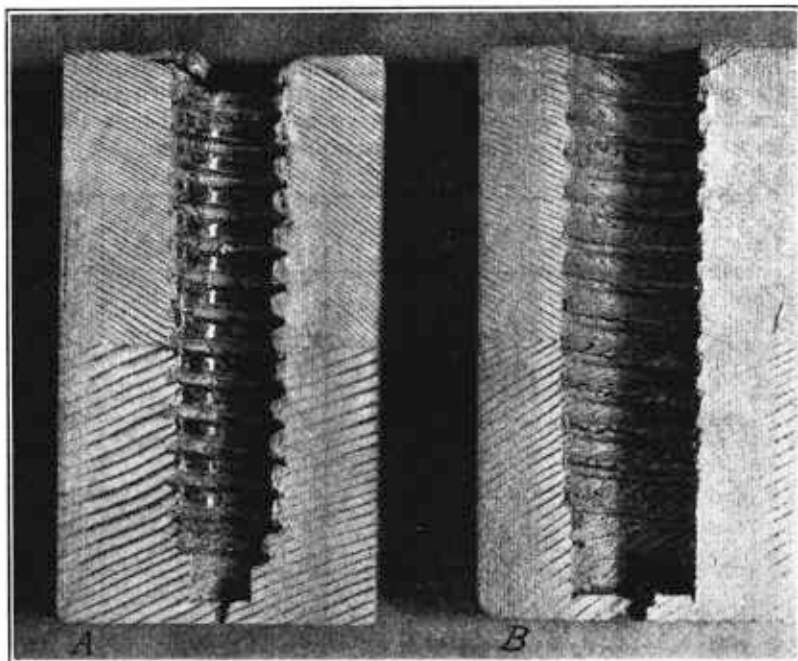


FIGURE 5.—*A*, Smooth, compact surface made by lag screw when driven into a lead hole of proper size; *B*, condition of surface when lead hole was too large.

#### DEPTH OF PENETRATION OF LAG SCREWS

In the tests to determine the influence of depth of penetration of a lag screw into the member receiving the point, three sizes of lag screws, one-half, five-eighths, and three-fourths inch, were used with redwood. With northern white pine, Douglas fir, and white oak only lag screws of  $\frac{3}{8}$ -inch shank diameter were used. The screws were tested at effective depths of 1, 2, 3, and 4 inches. The reduced portion near the point of the screw was not considered in determining the effective depth.

It may be seen in figure 6 that when only a threaded portion of the screw is embedded in the wood, the resistance to direct withdrawal of lag screws of any given diameter and any given species of wood varies directly as the depth of penetration. Therefore, all direct-withdrawal test loads, are reduced to pounds per inch of penetration. In the oak, at a depth of 4 inches, the resistance to withdrawal exceeded the ultimate tensile strength of the  $\frac{3}{8}$ -inch lag screw, hence no values for this depth are recorded for oak. No tests were made for northern white pine and Douglas fir at the 4-inch depth.

## SPECIFIC GRAVITY

Although the strength properties of wood, such as hardness, compression parallel and compression perpendicular to the grain, determine

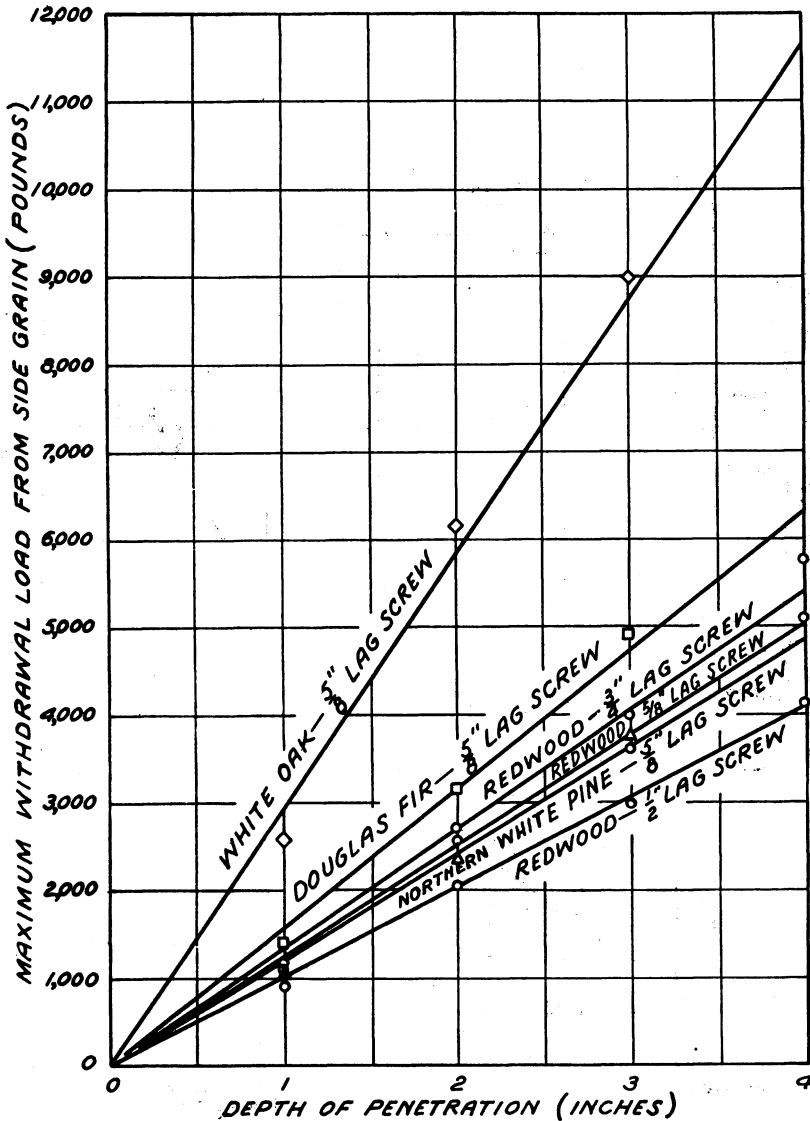


FIGURE 6.—Resistance of lag screws to direct withdrawal for different depths of penetration using optimum diameter of lead hole.

its behavior in supporting the fastening; no single property is as good a criterion of the resistance to direct withdrawal of a lag screw as the specific gravity of the wood.

Figure 7 shows that the resistance to withdrawal of lag screws varies approximately as the  $3/2$  power of the specific gravity of the wood. All measurements of specific gravity are based on oven-dry

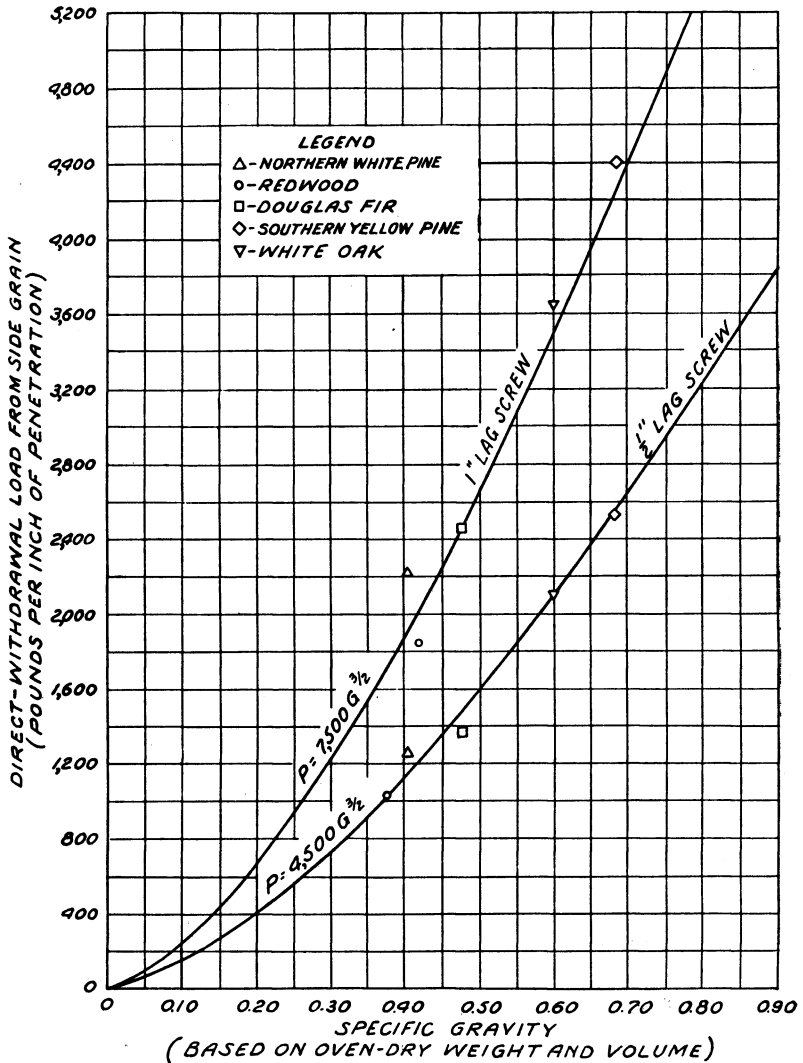


FIGURE 7.—Relation between direct-withdrawal loads of different diameter lag screws and specific gravity of the wood. The moisture content of the wood was about 9 percent.

weight and volume when oven-dry. For convenience in preparing the curves, the load points for the different species at about 9-percent moisture content are plotted for only two diameters of screws, namely one-half and 1 inch.

## DIAMETER OF LAG SCREW

A rather close relation exists between the resistance to withdrawal of lag screws and their diameters (table 1). Figure 8 shows that for

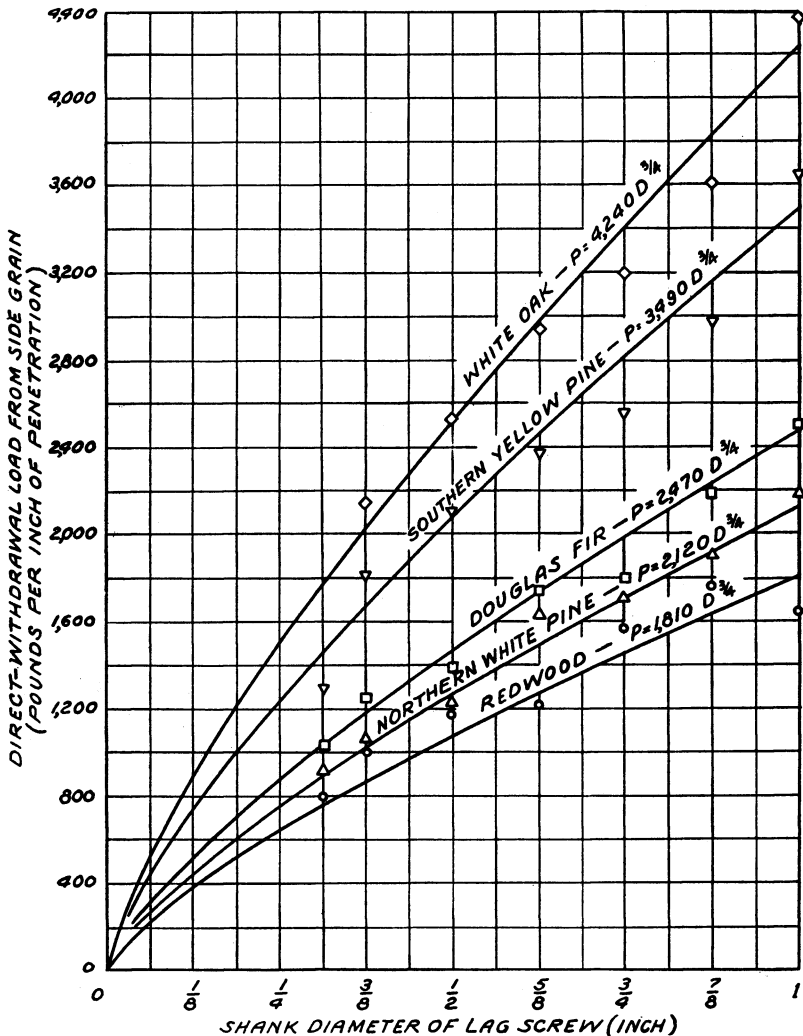


FIGURE 8.—Resistance of lag screws of different diameters to direct withdrawal. The moisture content of the wood was about 9 percent.

a given species and quality of wood the withdrawal loads per inch of penetration vary about as the  $3/4$  power of the diameter of the lag screw.



White oak ----	6	3/8	9/32	.36	.75	3.22	7,820	10.4	.683	6,921	-----	2,149	2,140	.996	Cull: Lag screws broke in tension.
	6	1/2	3/8	.48	.75	3.19	7,820	10.4	.683	8,071	-----	2,530	2,520	.996	Slight splintering in driving.
	16	5/8	15/32	.62	.75	3.08	7,592	10.3	.678	8,987	-----	2,918	2,938	1.007	Split in driving and some splintering.
	6	3/4	7/16	.73	.75	3.03	7,820	10.4	.683	9,742	-----	3,215	3,202	.996	Splintering in driving.
	6	7/8	21/32	.85	.75	2.96	7,820	10.4	.683	10,746	-----	3,630	3,615	.996	Slight split in driving.
	6	1	3/4	.97	.75	2.83	7,820	10.4	.683	12,453	-----	4,400	4,382	.996	Split in driving.

<sup>1</sup> Threaded portion in actual contact with wood.

<sup>2</sup> Based on weight and volume when oven dry.

<sup>3</sup> Loads adjusted to an average specific gravity by  $G^{3/2}$ .

<sup>4</sup> Corresponding values for end grain penetration: 1,177 pounds unadjusted; 1,242 pounds adjusted.

<sup>5</sup> Corresponding values for end grain penetration: 891 pounds unadjusted; 833 pounds adjusted.

<sup>6</sup> Corresponding values for end grain penetration: 1,269 pounds unadjusted; 1,227 pounds adjusted.

## COMBINED INFLUENCE OF SPECIFIC GRAVITY AND DIAMETER OF LAG SCREW

The combined influence of diameter of lag screw and specific gravity of the wood is expressed by the formula:

$$P = KD^{3/4}G^{3/2}$$

in which  $P$  represents ultimate withdrawal load per inch of penetration of lag screw;  $K$  represents a constant which for the species tested was found to be 7,500;  $D$  represents shank diameter of lag screw in inches; and  $G$  represents specific gravity of the wood based on oven-dry weight and volume when oven dry.

The curves in figure 9 show the ultimate withdrawal loads per inch of penetration that may be expected for lag screws ranging from one-quarter to 1 inch in shank diameter when pulled from wood of any specific gravity. By means of this set of curves the approximate ultimate loads of lag screws for any species may be determined from its specific gravity without material error. Horizontally opposite the intersections of any solid vertical line representing the specific gravity of the species with the curve representing the diameter of lag screw will be found the ultimate withdrawal load per inch of penetration for the particular species of this specific gravity and for the given diameter of lag screw.

The curves in figure 9 have a very practical and convenient application to the problem of lag-screw joints. The designer usually knows the kind of timber he is to use and also the sizes of lag screw. Then by following the vertical line on the chart that represents the specific gravity of the material to the intersection with the curve for the diameter of screw and then following a horizontal line to the margin at the left, the ultimate withdrawal load per inch of penetration of the threaded portion of the screws will be found. About one-fifth of this load will be the safe load to use. Dividing the load to be supported by the safe load per inch of screw will give the required threaded portion penetrating the main member. Dividing this total length by the amount of thread on each screw in contact will give the number of screws required.

For greater convenience in applying figure 9, table 2 is presented which gives the values for specific gravity of the more important structural species. The resistance to withdrawal of a lag screw from an end-grain surface was found to be about three-fourths as great as from a side-grain surface.

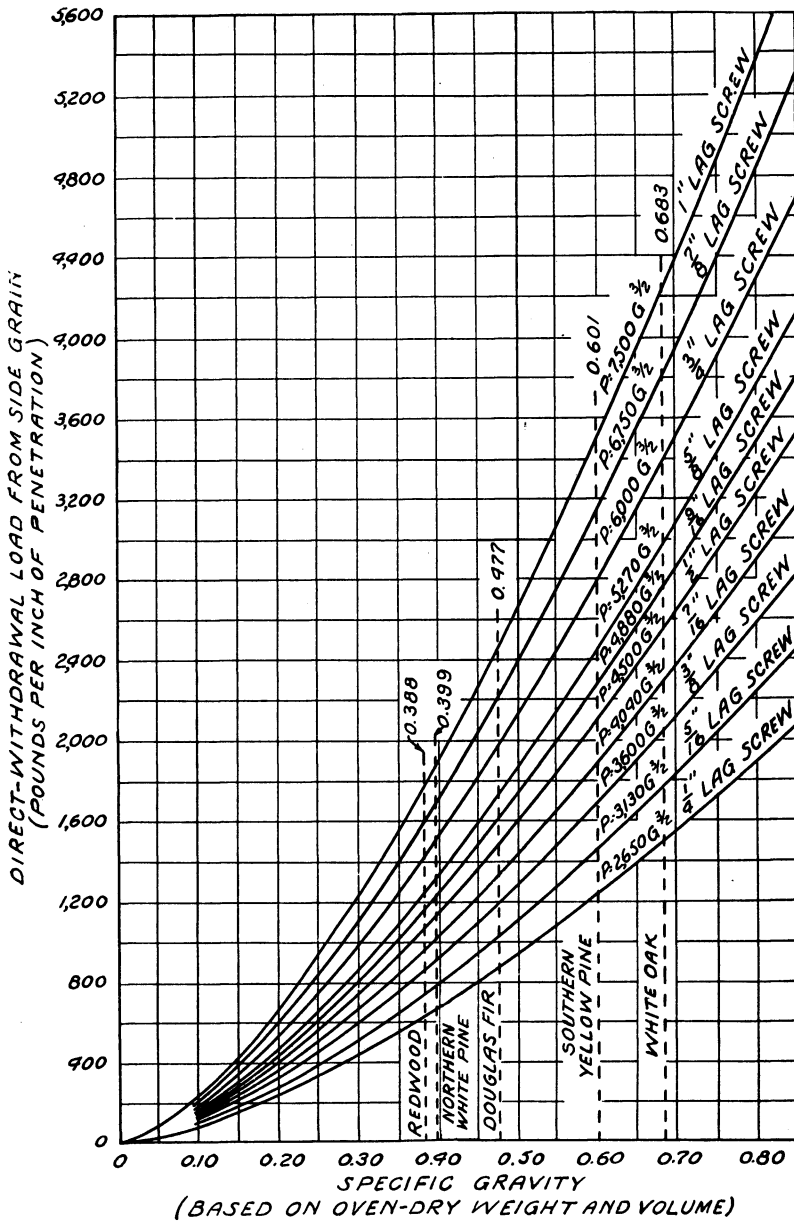


FIGURE 9.—Relation between direct-withdrawal loads of lag screws of different diameters and specific gravity of the wood. The moisture content of the wood was about 9 percent.

TABLE 2.—*Specific gravity of commercially important species of wood*<sup>1</sup>

Species	Specific gravity	Species	Specific gravity
Hardwoods:		Hardwoods—Continued.	
Alder, red	0.43	Oak	0.68
Ash, black	.53	Poplar, yellow	.43
Ash, white	.64	Sycamore	.54
Aspen	.40	Walnut, black	.56
Basswood	.40	Willow, black	.41
Birch, yellow	.66	Conifers:	
Buckeye, yellow	.38	Cedar, northern white	.32
Butternut	.40	Cedar, Port Orford	.44
Cherry, black	.53	Cedar, western red	.34
Chestnut	.45	Cypress, southern	.48
Cottonwood, eastern	.43	Douglas fir	.51
Cucumber magnolia	.52	Fir, commercial white	.42
Elm, American	.55	Hemlock, eastern	.43
Elm, rock	.66	Hemlock, western	.44
Gum, black	.55	Larch, western	.59
Gum, red	.53	Pine, northern white	.37
Gum, tupelo	.52	Pine, ponderosa	.42
Hackberry	.56	Pine, southern yellow	.58
Hickory	.72	Redwood	.39
Locust, black	.71	Spruce	.39
Madrone	.69	Tamarack	.56
Magnolia, evergreen	.53		
Maple, hard	.68		
Maple, soft	.51		

<sup>1</sup> Weight and volume when oven dry.

### LATERAL RESISTANCE OF LAG SCREWS

In lateral resistance, a lag screw functions very much like a bolt in holding the members of a joint in place. There are two distinct differences, however, that must be considered in order to understand properly lag-screw action, namely; a threaded portion of the lag screw, in lieu of a nut, to hold it in place and resist direct withdrawal; a difference in cross section of the shank and threaded portion of a lag screw, instead of a uniform section as in a bolt. It is evident that a lag screw must have sufficient depth of penetration to take the load without pulling, whereas a bolt can be short and heavy because the nut will hold it in place. On account of these differences between the action of lag screws and bolts, the analysis of the test data must be on a somewhat different basis than that for bolts. Nevertheless, when these differences are considered the lag-screw data correlate very closely with deductions previously derived from a more intensive study of bolts.<sup>4</sup>

### MATERIALS AND TEST PROCEDURE

Air-dried material representing northern white pine, southern yellow pine, Douglas fir, and white oak was used in this part of the study. It was very similar to the material used for direct-withdrawal tests.

The lag screws varied in ultimate tensile strength from 62,000 to 101,000 pounds per square inch. A tensile strength of 77,000 pounds per square inch was taken as an average in developing an adjustment factor to correct for this difference in the quality of the screws.

Tests for but one condition of seasoning were made, and for only one direction of loading, parallel to the grain of the wood. Each specimen consisted of two members, a cleat and a block of the same-species,

<sup>4</sup> TRAYER, G. W. THE BEARING STRENGTH OF WOOD UNDER BOLTS. U. S. Dept. Agr. Tech. Bull. 332, 40 pp., illus. 1932.

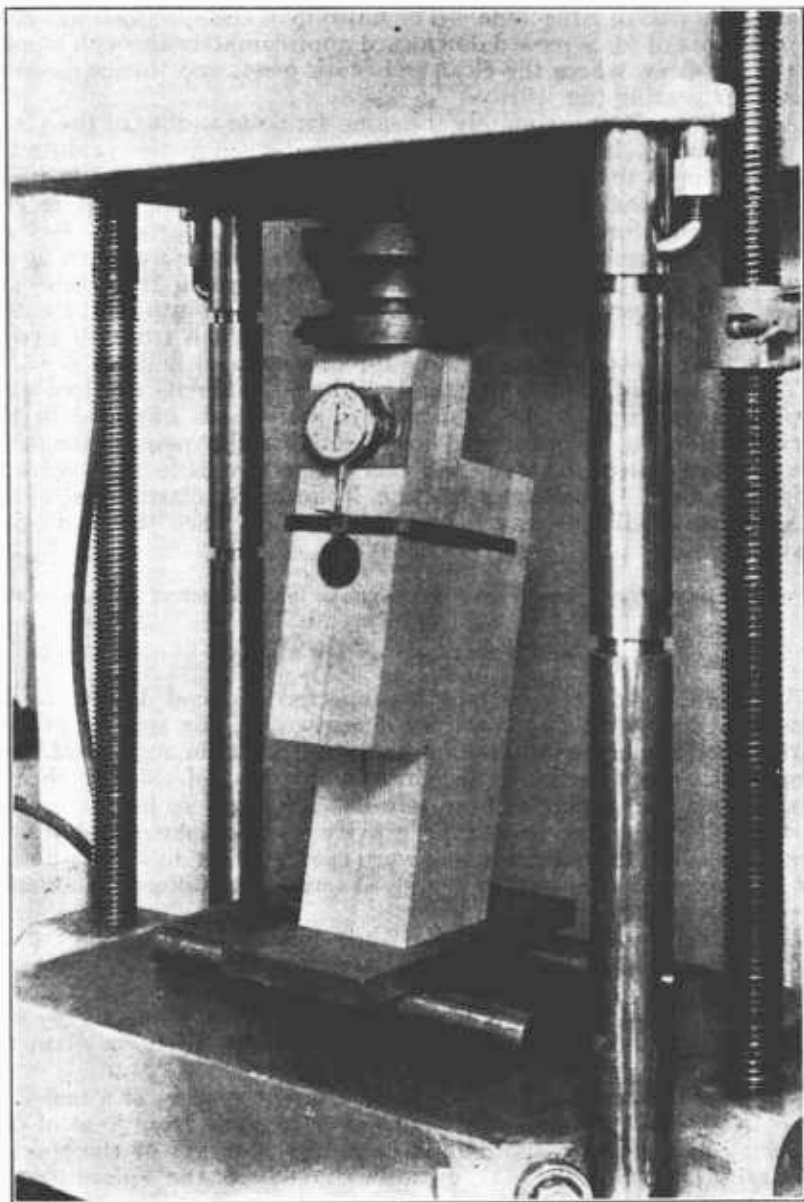


FIGURE 10.—Method of testing lag screws for lateral resistance.

joined by a lag screw passing through the cleat and into the block. In most of the tests wooden cleats were used, but in a few tests metal plates were substituted for the wood cleats.

The load was applied parallel to the grain of the wood, by means of a laboratory testing machine. The position of the specimen was such that the line of force passed downward approximately through a point in the lag screw where the cleat and block meet, and thence down to the lower bearing (fig. 10).

A lead hole of approximately the same diameter as that of the shank of the screw was bored through the cleat and when necessary, into the block as far as the shank extended. The lead hole was continued in the block for the threaded portion, its diameter being that recommended earlier for a given size of screw used with a particular species.

A speed of machine of about 0.015 inch per minute was used in the tests to beyond the proportional limit, after which the speed was increased at intervals to 0.031 and 0.05 inch per minute until the test was completed. Deflections for increments of load from 50 to 100 pounds were plotted to well above the proportional limit.

The analysis of the test data and all the adjustments required were applied, primarily, to the proportional limit loads obtained in the tests. The term, "proportional limit", refers to that point in the stress strain curve, where the loads and their respective deflections cease to be proportional. For lag screws, this is not a true elastic limit of the joint, since it will not return to zero deflection when the load is removed.

#### FACTORS THAT AFFECT RESISTANCE TO LATERAL DISPLACEMENT OF LAG-SCREW JOINTS

##### SPECIFIC GRAVITY OF THE WOOD

Although the different strength properties of wood determine the resistance to lateral displacement of lag screws, the specific gravity of the wood is a better criterion of its magnitude than any one of these properties. To determine the nature and extent of the influence of specific gravity, specimens from representative species having a comparatively wide range in specific gravity were prepared and tested. Lag screws of different diameters were used in order to show whether the effect of specific gravity of the wood varied with different diameters of screws.

In one series of tests, northern white pine, southern yellow pine, and Douglas fir were the species used and in a second series, white oak was substituted for the Douglas fir. In the first series a uniform thickness of cleat 1½ inches was used with all sizes of lag screw, and in the second series, the ratio of cleat thickness to shank diameter of screw was kept constant at 4 to 1.

The proportional limit loads for the different species, at a moisture content of about 10 percent, were found to vary regardless of the diameter of lag screw approximately as the  $\frac{3}{4}$  power of the specific gravity of the wood (fig. 11), or approximately as the square root of the crushing strength of the wood along the grain. The results for northern white pine are a trifle high for the specific gravity and those for white oak somewhat lower than the specific gravity would indicate.

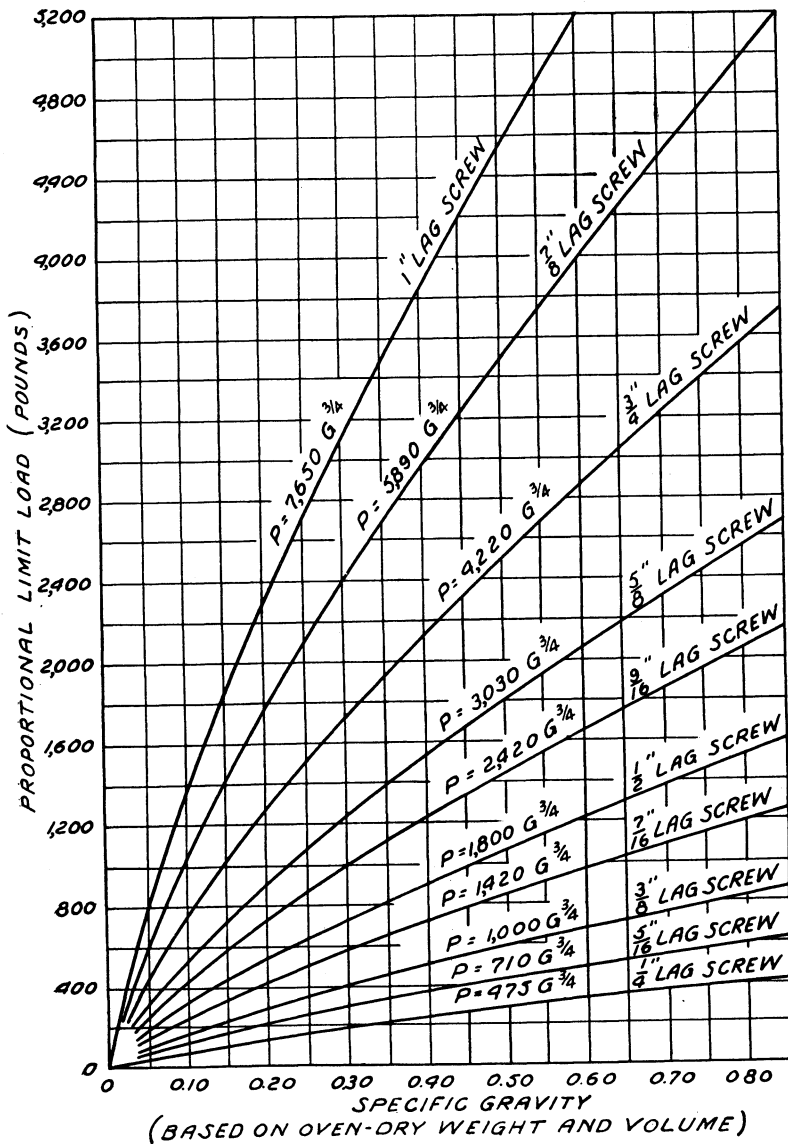


FIGURE 11.—Relation between resistance to lateral displacement of lag screws of different diameters and the specific gravity of the wood. The screws penetrated a side-grain surface of specimens having a moisture content of about 10 percent.

TABLE 3.—Resistance of lag screws to lateral displacement in northern white pine

[Thickness of cleat and length of screw varied; diameter <sup>1</sup> of lag screw five-eighths of an inch]

Thickness	Cleat			Block			Cleat and block			Lag screws			Load			Remarks
	Crushing strength parallel to grain	Specific gravity <sup>2</sup>	Moisture content	Crushing strength parallel to grain	Specific gravity <sup>2</sup>	Moisture content	Crushing strength parallel to grain	Specific gravity <sup>2</sup>	Moisture content	Length of shank	Length of shank in block	Effective length of threaded portion	Proportional limit		Maximum	
	At test	Adjusted <sup>3</sup>		At test	Adjusted <sup>3</sup>		At test	Adjusted <sup>3</sup>								
<i>Inches</i>	<i>Lbs. per sq. in.</i>		<i>Percent</i>	<i>Lbs. per sq. in.</i>		<i>Percent</i>	<i>Lbs. per sq. in.</i>		<i>Percent</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Pounds</i>	<i>Pounds</i>	<i>Pounds</i>	
1.0	4,831	0.336	11.6	5,790	0.385	11.0	5,310	0.360	11.3	2.80	1.68	4.05	1,600	1,335		Cleat split. Do. Do. Limit of test. Cleat split. Do. Screw pulled. Do.
1.0	4,831	.336	11.6	5,790	.385	11.0	5,310	.360	11.3	2.76	1.64	4.10	( <sup>4</sup> )	-----	-----	
1.0	4,831	.336	11.6	5,790	.385	11.0	5,310	.360	11.3	2.80	1.68	4.08	1,500	1,250	-----	
1.0	4,831	.336	11.6	5,790	.385	11.0	5,310	.360	11.3	2.79	1.67	4.06	1,550	1,295	-----	
Average <sup>5</sup> 1.0	4,831	.336	11.6	5,790	.385	11.0	5,310	.360	11.3	2.79	1.67	4.07	1,550	1,293	-----	
2.0	6,450	.376	11.0	6,075	.387	10.6	6,262	.381	10.8	4.40	2.25	5.46	1,700	1,285	7,320	
2.0	6,800	.367	10.1	6,075	.404	10.6	6,437	.385	10.3	4.40	2.25	5.54	1,800	1,350	5,870	
2.0	6,260	.367	10.6	6,075	.387	10.6	6,167	.377	10.6	3.90	1.75	5.01	1,700	1,360	6,730	
2.0	6,920	.418	9.5	6,075	.387	10.6	6,497	.402	10.0	3.90	1.75	4.99	2,000	1,520	7,500	
2.0	8,940	.426	7.1	7,533	.400	7.3	8,236	.413	7.2	3.20	1.05	4.72	1,600	1,305	6,590	
2.0	7,520	.353	6.1	7,533	.400	7.3	7,526	.376	6.7	3.25	1.10	4.66	1,700	1,475	6,040	
2.0	6,360	.400	7.6	6,423	.353	8.8	6,391	.376	8.2	2.85	.70	3.99	1,500	1,375	6,460	
2.0	8,170	.423	7.5	6,423	.354	8.0	7,298	.388	7.7	2.85	.70	3.96	1,500	1,345	6,130	
Average <sup>6</sup> 2.0	7,177	.391	8.7	6,527	.384	9.2	6,852	.387	8.9	3.59	1.44	4.79	1,687	1,377	6,580	
2.5	5,860	.340	9.3	6,075	.387	10.6	6,467	.363	9.9	4.40	1.75	5.51	1,900	1,560	5,060	Limit of test. Cleat split. Limit of test. Cleat split. Limit of test. Do. Screw pulled. Do.
2.5	6,435	.396	9.2	6,075	.387	10.6	6,255	.391	9.9	4.40	1.75	5.46	1,800	1,400	8,000	
2.5	6,100	.340	7.3	6,562	.380	7.7	6,331	.360	7.5	3.92	1.27	4.94	1,800	1,580	6,050	
2.5	6,080	.330	7.3	7,120	.362	7.2	6,600	.346	7.2	3.90	1.25	4.91	1,800	1,630	6,150	
2.5	5,315	.336	10.4	5,415	.400	12.4	5,365	.368	11.4	3.20	.55	4.72	1,800	1,705	7,060	
2.5	6,090	.410	10.3	5,695	.396	11.1	5,892	.402	10.7	3.27	.62	4.65	( <sup>4</sup> )	-----	8,200	
2.5	6,570	.332	6.8	6,290	.358	8.8	6,430	.345	7.8	2.85	.20	3.96	1,600	1,665	5,870	
2.5	7,670	.404	6.8	7,120	.362	7.2	7,395	.383	7.0	2.88	.14	3.93	1,600	1,550	5,910	
Average <sup>7</sup> 2.5	6,265	.361	8.4	6,294	.379	9.4	6,342	.370	8.9	3.60	.94	4.76	1,757	1,584	6,538	
3.0	6,025	.385	10.3	6,075	.387	10.6	6,050	.386	10.4	4.42	1.27	5.47	2,100	1,750	8,600	Limit of test. Do. Screw pulled. Limit of test.
3.0	6,195	.361	5.6	6,562	.380	7.7	6,378	.370	6.6	4.40	1.25	5.53	1,700	1,465	7,970	
3.0	6,000	.374	10.2	5,415	.400	12.4	5,708	.387	11.3	4.00	.85	4.90	1,900	1,675	8,030	
3.0	6,140	.381	9.8	5,695	.396	11.1	5,917	.388	10.4	3.90	.70	4.97	2,000	1,795	8,920	

	3.0	6,195	.361	5.6	6,427	.354	8.0	6,311	.357	6.8	3.20	.05	4.69	(4)		6,710	Screw pulled.
	3.0	7,000	.370	6.7	6,423	.353	8.8	6,711	.361	7.7	3.25	.10	4.65	1,800	1,840	7,200	Do.
	3.0	6,000	.366	9.3	6,887	.382	8.7	6,443	.374	9.0	2.85	0	3.94	1,700	1,710	5,300	Do.
	3.0	6,620	.385	7.0	6,887	.382	8.7	6,753	.383	7.8	2.85	0	3.95	2,000	1,975	5,570	Do.
Average <sup>8</sup>	3.0	6,272	.373	8.1	6,296	.379	9.5	6,284	.376	8.7	3.61	.53	4.76	1,886	1,744	7,288	
	3.5	6,145	.379	10.4	5,600	.395	10.9	5,872	.387	10.6	4.44	.79	5.47	2,100	1,865	6,380	Screw pulled.
	3.5	5,470	.370	11.2	5,862	.389	11.0	5,666	.379	11.1	4.44	.79	5.47	1,600	1,445	6,860	Limit of test.
	3.5	7,310	.374	6.7	6,408	.364	7.1	6,859	.369	6.9	4.40	.75	5.52	1,900	1,755	8,660	Screw pulled.
	3.5	6,750	.386	6.8	6,408	.365	7.1	6,579	.375	6.9	4.40	.75	5.48	2,200	2,010	8,070	Do.
	3.5	6,240	.382	9.4	5,600	.395	10.9	5,920	.388	10.1	4.00	.35	4.89	1,900	1,780	7,960	Do.
	3.5	5,400	.370	11.2	5,862	.389	11.0	5,631	.379	11.1	4.00	.35	4.98	(4)		8,100	Do.
	3.5	6,765	.376	6.4	6,637	.409	8.4	6,701	.392	7.4	3.90	.26	5.00	1,800	1,690	6,680	Cleat split.
	3.5	7,015	.351	6.3	6,637	.409	8.4	6,826	.380	7.3	3.93	.30	4.94	2,000	1,915	6,250	Do.
	3.5	6,175	.363	8.6	6,490	.371	7.4	6,332	.367	8.0	3.20	0	4.73	(4)		6,190	Screw pulled.
	3.5	6,695	.374	6.5	6,490	.371	7.4	6,592	.372	6.9	3.30	0	4.57	1,900	1,920	6,650	Do.
Average <sup>9</sup>	3.5	6,396	.372	8.3	6,199	.386	9.0	6,298	.379	8.6	4.00	.43	5.10	1,925	1,798	7,174	
	4.0	5,790	.385	11.0	5,790	.385	11.0	5,790	.385	11.0	4.40	.28	5.50	1,900	1,805		
	4.0	5,790	.385	11.0	5,790	.385	11.0	5,790	.385	11.0	4.40	.28	5.44	1,800	1,710		
Average <sup>10</sup>	4.0	5,790	.385	11.0	5,790	.385	11.0	5,790	.385	11.0	4.40	.28	5.47	1,850	1,758		

<sup>1</sup> Diameter of lag screw refers to the diameter of the shank of the screw. A lead-hole diameter approximately 60 percent of that of the shank was used for the threaded portion of the screw and about 100 percent for the shank portion.

<sup>2</sup> Based on weight and volume when oven dry.

<sup>3</sup> Adjustment for differences in length of shank in block is based on fig. 14. The adjustment for a given specific gravity to an average specific gravity of 0.377 is based on fig. 11.

<sup>4</sup> Cull.

<sup>5</sup> Deflection at proportional limit load 0.014 inch.

<sup>6</sup> Deflection at proportional limit load 0.048 inch; at maximum load 2.6 inches.

<sup>7</sup> Deflection at proportional limit load 0.061 inch; at maximum load 2.6 inches.

<sup>8</sup> Deflection at proportional limit load 0.053 inch; at maximum load 2.7 inches.

<sup>9</sup> Deflection at proportional limit load 0.053 inch; at maximum load 2.5 inches.

<sup>10</sup> Deflection at proportional limit load 0.055 inch.

## DIAMETER OF LAG SCREW

The proportional limit loads for all woods tested were found to vary as the square of the diameter of the screw. This relation between diameter of lag screw and proportional limit load is illustrated by figure 12, which is for northern white pine. The term "diameter" refers to the diameter of the shank or unthreaded portion of the lag screw.

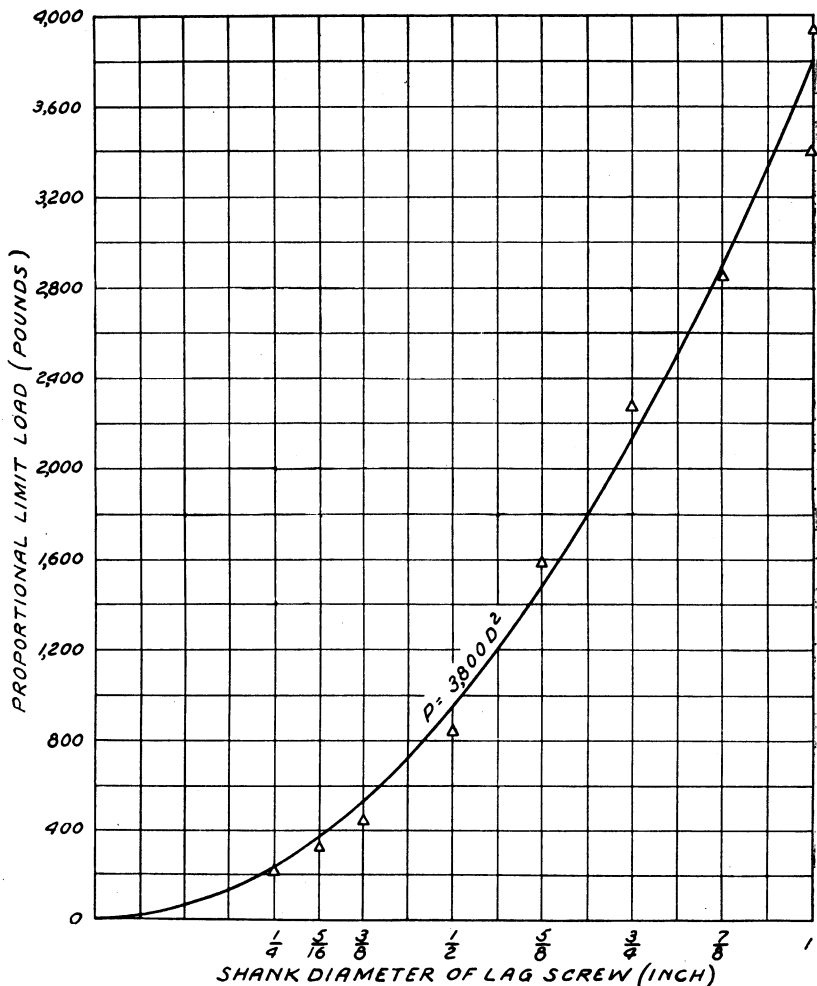


FIGURE 12.—Relation between the diameter of lag screw and the resistance to lateral displacement in northern white pine at about 10-percent moisture content. The screws penetrated a side-grain surface of the specimen.

The resistance to lateral displacement of a lag screw bearing parallel to the grain of the wood was also found to vary about as the square root of the yield point stress of the metal.

## THICKNESS OF CLEAT

One group of tests of northern white pine, recorded in table 3 was made primarily to show how differences in cleat thickness affect the

strength and stiffness of a lag-screw joint. Cleat thicknesses ranging by small increments from 1 to 4 inches were used with a 5/8-inch lag screw.

A decided increase in load occurred with an increase in the ratio of cleat thickness to the shank diameter of lag screw up to about 7 to 1, beyond which but little increase in the proportional limit loads is obtained. Below a 3.5 to 1 ratio the loads were somewhat irregular, and at a ratio of about 2 to 1 they became very erratic.

The results are shown graphically in figure 13. This curve, in order to make it applicable to the results obtained with other species and sizes of lag screws than those tested, was developed on the basis of percentage change in load with change in cleat-thickness ratio, the loads being expressed as a percentage of the load for a cleat-thickness ratio of 3.5 to 1, which appears to be a practical ratio. The more

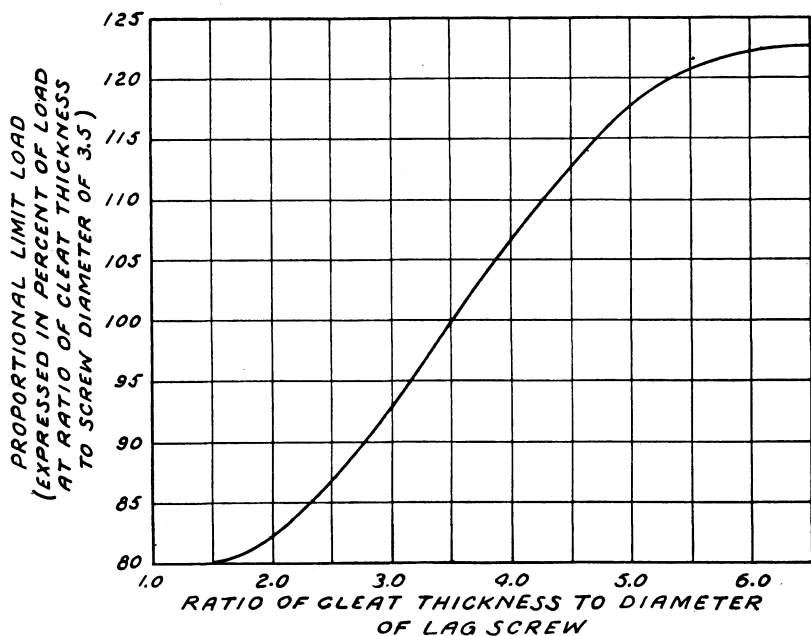


FIGURE 13.—Influence of difference in the ratio of cleat thickness to diameter of shank on the proportional limit loads of lag screws penetrating a side-grain surface.

general application of the curve will lead to no appreciable error in any adjustment of results.

#### DEPTH OF LAG SCREW IN THE BLOCK

If a constant ratio of cleat thickness of about 3.5 is used with lag screws of different diameters, a depth of penetration in the main member of the joint of about 7 times the diameter of the lag screw for the harder woods and about 11 or 12 times for the softer species is required to develop the full strength of the joint. Higher cleat-thickness ratios up to about a 7 to 1 require greater depths of penetration. For the smaller cleat-thickness ratios resulting from the use of thin cleats the depth of penetration may also be reduced. The proportional limit loads are not affected until the depth of penetration is less than about 5 times the diameter of lag screw.

## LENGTH OF SHANK IN BLOCK

From tests made on northern white pine, using a 5/8-inch lag screw, and three different depths of penetration of shank in the block, namely: 2.25, 0.7, and 0.1 inches, and from the results of lateral resistance tests of bolts<sup>5</sup> previously made, a curve, figure 14, was derived that illustrates the approximate influence of the "length of shank in block" on the behavior of a lag-screw joint. This is a percentage curve, the point representing the load at zero penetration of shank into the block being taken as 100 percent. The curve shows the percentage increase in proportional-limit load that accompanies an increase in the length of shank in the block.

The correct form of this curve depends upon the quality of the wood and of the lag screw and somewhat upon the design of the screw, but no material error is involved in the use of the curve in adjustment of results where other qualities of both wood and metal than those represented in the tests are used. Beyond a ratio of depth of shank to the

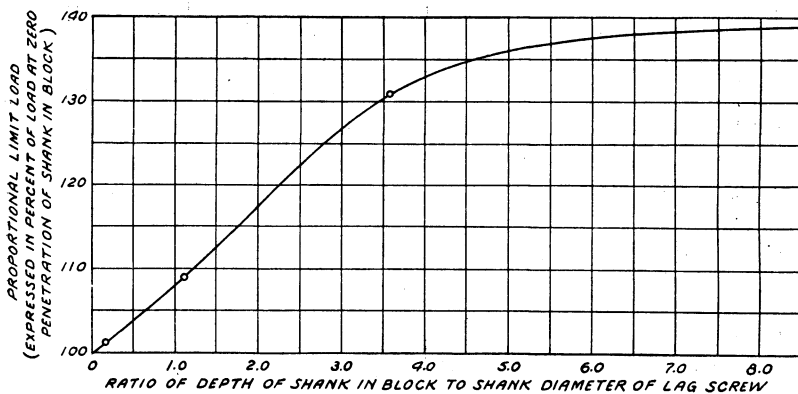


FIGURE 14.—Influence of the length of shank in the block on the proportional-limit loads of lag screws penetrating a side-grain surface.

diameter of screw of about 7 to 1, which gives an increase in proportional-limit load of 39 percent, there is no further improvement in strength with increased length of shank in the block.

Although no tests of lag-screw joints where the shank of the screw failed to penetrate entirely through the cleat were made, it may be easily conceived that this lack of penetration would reduce the loads otherwise obtained with complete penetration as much as 20 percent or to the same load that would be obtained with a bolt having a diameter equal to that of the lag screw at the root of the thread.

## METAL CLEATS

To determine the influence of metal cleats, tests were made on northern white pine, southern yellow pine, and white oak, using a 5/8-inch lag screw and a metal plate one-half inch thick. The method of test was about the same as that for wooden cleats. The proportional limit loads were found to be about 25 percent higher using metal cleats than for the same species tested with wooden cleats. The differences in thickness of metal plates likely to be used with lag screws will have very little influence on the loads.

<sup>5</sup> TRAYER, G. W. See footnote 4, p. 14.

## DEFORMATION OF LAG SCREWS

The influence of quality of the wood and of the metal in the screws, the thickness of the cleat, and the extent of penetration of the shank portion into the block is reflected in the deformation of the lag screws. Figure 15 shows a type of deformation of screw when metal plates were used in test.

Since, with bolts and lag screws, it appears that the proportional limit of the joint is reached when the bolt or screw passes its proportional limit, a study of these deformations of lag screws reveals how

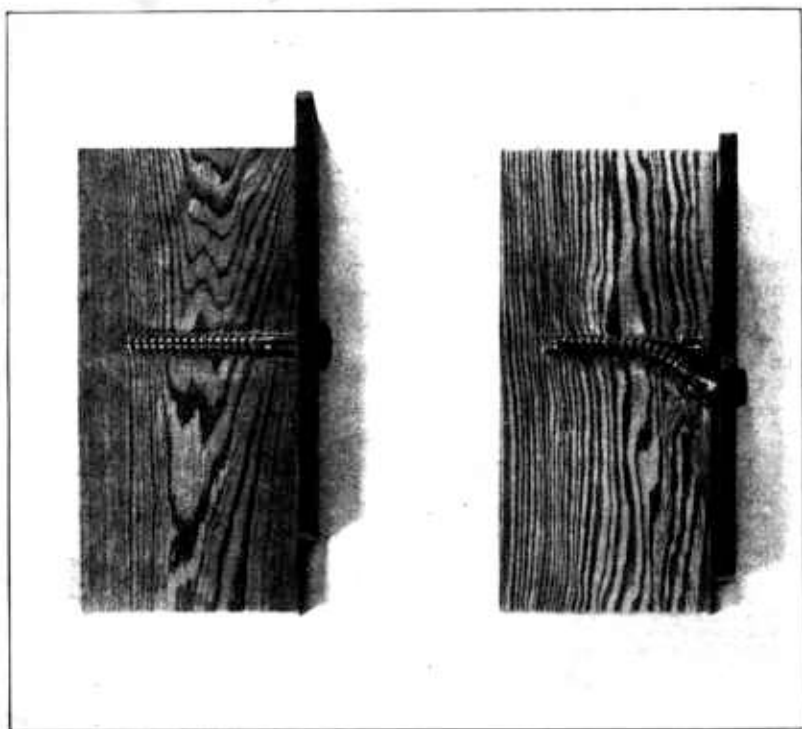


FIGURE 15.—Cutaway sections of southern pine showing  $\frac{1}{2}$ -inch lag screws and metal cleats: Left, condition of screw before test; right condition after test.

thickness of cleat and the other variables mentioned influence the results. With softwoods, for instance, when a thin cleat was used, there is a single bend in the lag screw near the surface of the block (fig. 16). With a thick cleat, there is a reverse bend in the shank portion and also a single bend within the block, farther back than with a thin cleat. When the shank of the lag screw extends only a short distance into the main member the bend in the screw takes place at the beginning of the thread, but with a considerable depth of shank in the block the bend develops in the shank of the screw. With the denser woods these same types of bends are repeated but the bends are sharper and shorter.

SAFE LATERAL LOADS FOR LAG-SCREW JOINTS

Equations for use in calculating safe loads for lag screws of different sizes, used with different species of wood, are given in table 4. The relations expressed in the general equation previously referred to,  $P=KD^2$ , were used in the determination of these safe loads. In the equation,  $\bar{P}$  represents the proportional limit load and becomes  $P_1$

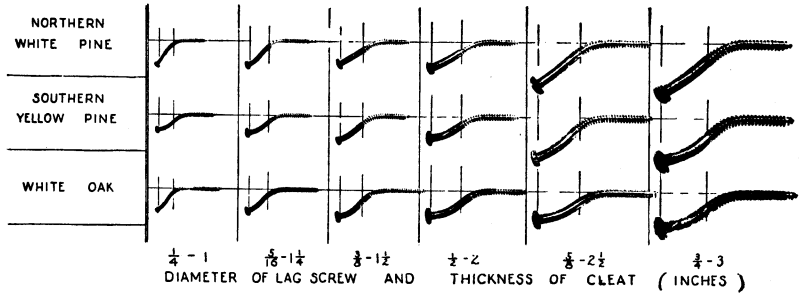


FIGURE 16.—Typical failures of lag screws in lateral resistance with three species of wood.

representing the safe load of a lag-screw joint of dry wood, with the bearing parallel to the grain of the wood;  $K$  becomes  $K_1$ , a constant, and  $D$ , the diameter of the shank of the screw in inches.

TABLE 4.—Equations for computing safe lateral loads for lag screws driven into side grain

Group	Species of wood	Equation <sup>1</sup>	Group	Species of wood	Equation <sup>1</sup>
1	Cedar, northern and southern white.....	$P_1=1,500D^2$	3	Ash, black.....	$P_1=1,900D^2$
	Fir, balsam and commercial white.....			Birch, paper.....	
	Hemlock, eastern.....			Douglas fir (Coast type).....	
	Pine, ponderosa, sugar, northern white, and western white.....			Elm (soft), American and (grey) slippery.....	
	Spruce, Engelmann, red, Sitka, and white.....			Gum, black, red, and tupelo.....	
	Aspen, and largetooth aspen.....			Larch, western.....	
	Basswood.....			Maple, (soft) red and silver.....	
	Cedar, Alaska, Port Orford, and western red.....			Pine, southern yellow.....	
	Chestnut.....			Sycamore.....	
	Cottonwood, black and eastern.....				
2	Cypress, southern.....	$P_1=1,700D^2$	4	Ash, commercial white.....	$P_1=2,200D^2$
	Douglas fir (Rocky Mountain type).....			Beech.....	
	Hemlock, western.....			Birch, sweet and yellow.....	
	Pine, Norway.....			Elm, rock.....	
	Redwood.....			Hickory, true and pecan.....	
	Tamarack.....			Maple (hard), black and sugar.....	
	Yellow poplar.....			Oak, commercial red and white.....	

<sup>1</sup> The equations refer to lag-screw joints having a cleat thickness 3.5 times the shank diameter of the screw and a depth of penetration of the screw in the main member varying from 11 times this diameter for group 1 woods to 7 times for group 4 woods. With other cleat-thickness ratios and various lengths of shank in the block, apply the corrections indicated by figures 13 and 14. The values in the table assume that the shank of the screw extends to the surface of contact between the cleat and block. If the shank fails to extend this far in the cleat the loads may decrease as much as 20 percent. The safe loads also apply to lag screws having a yield point of 45,000 pounds per square inch used with timber at about 15-percent moisture content. When the timber is occasionally wet but quickly dried the safe loads above should be reduced one-fourth. If damp or wet most of the time they should be reduced one-third. If screws of a different quality of metal are used, adjust the loads by applying as a factor the square root of the ratio of the yield point of the given metal to 45,000.  $D$  in the equations refers to the shank diameter of the screw. When metal cleats are used these loads may be increased 25 percent.

The constant  $K_1$ , in the equations, was obtained by adjusting the proportional limit loads of species representative of the groups of woods to values 20 percent above the average value for green material of the same species in order to allow for an increase in strength with drying, then dividing by a factor 2.25, to take care of variability of the material, checking around the screw, and overload. All values are based on a yield point in the metal of the screws of 45,000 pounds per square inch.

For any group of species not represented in the tests and for which there is no average value from which to derive a safe load for the group, as just explained, the safe load was obtained by applying as a factor to the constant for one of the other groups, the  $3/4$  power of the ratio of the average specific gravity of that group to the average for the group under consideration.

For conditions other than those of the tests the safe loads are to be reduced as follows: When the timbers are occasionally wet but quickly dried, use only three-fourths of the given loads; if damp or wet most of the time, use two-thirds.

If a high-grade metal is used in the lag screws, change the safe loads by applying as a factor the square root of the ratio of the stress at yield point of the given metal, to a stress of 45,000 pounds per square inch.

With these safe loads it is assumed that the cleat-thickness ratio is constant for the various sizes of lag screws and never less than about 3.5 to 1. It is further assumed that the shank of the lag screw penetrates the cleat to the plane of contact with the block. When metal cleats are used instead of wooden, the safe loads given in the table may be increased 25 percent. Any differences in thickness and quality of metal plates used with lag screws will have very little influence on the loads.

If the shank portion extends into the main member of a joint, the proportional limit load, as well as the safe load, will be increased up to about 40 percent, depending upon the amount of penetration. If the shank of the screw extends only part way through the cleat, the loads, when compared with that for complete penetration, may be reduced as much as 20 percent.

## CONCLUSIONS AND RECOMMENDATIONS

In assembling wooden members with lag screws it is essential to use prebored holes except for the smaller screws in the softer species; and even there, it is considered good practice. The lead hole for the entire shank should be of the same diameter as the shank. The recommended diameter of lead hole for the threaded portion in northern white pine is 40 to 70 percent of the shank diameter of the screw, in Douglas fir and southern yellow pine 60 to 75 percent, and in white oak 65 to 85 percent of the shank diameter. The larger figure in each range applies to screws of the greater diameters. Soap or other lubricant should be used on the screws, particularly with the denser species, to facilitate driving and prevent damage to the screw. Lead holes slightly larger than those recommended for maximum efficiency should be used with lag screws of excessive length.

The resistance to direct withdrawal of lag screws varies about as the  $3/4$  power of the shank diameter of the screws, about as the  $3/2$  power of the specific gravity of the wood into which they are driven, and directly as the depth of contact of the threaded portion. A depth greater than 7 times the shank diameter of the screw in the denser species and 10 to 12 times in the softer species would develop a resistance approximately as great as the ultimate tensile strength of the screw.

The resistance to withdrawal of a lag screw from an end-grain surface is about three-fourths as great as from a side-grain surface of the same piece.

The resistance to lateral displacement of a lag screw bearing parallel to the grain of the wood varies about as the square root of the crushing strength of the wood along the grain and as the  $3/4$  power of its specific gravity. It also varies as the square of the shank diameter of the lag screw and about as the square root of the yield-point stress of the metal.

A cleat-thickness ratio below about 3.5 to 1 gives more or less erratic proportional limit loads. For ratios from 3.5 to 1 up to about 7 to 1 there is a considerable increase in proportional limit loads but beyond this ratio the rate of increase in strength drops very rapidly.

In arriving at some of the more general deductions given here, full advantage was taken of information obtained from a very comprehensive series of tests of bolted joints in which the action for the greater ratios of length of bolt in main timber to diameter is very similar to that of lag screws.

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